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NETWORK-CENTRIC RAILROADING UTILIZING INTELLIGENT RAILROAD SYSTEMS

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Abstract

Network-centric railroading and intelligent railroad systems represent a “unified theory of railroading” in which positioning systems, sensors, computers, advanced mathematical methods, and digital communications are used to collect, process, and disseminate information to improve the safety, security, and operational effectiveness of railroads. Intelligent Transportation Systems (ITS) for highways and mass transit are based on the same technologies, as are the National Airspace System and maritime vessel tracking systems. Major parcel delivery companies, pipeline operators, law enforcement, and emergency response services also use these technologies. Military services utilize these technologies for network-centric warfare;¹ railroads will use them for network-centric railroading. Intelligent railroad systems can either be implemented as independent systems, in which case their benefits will be limited, or they can be implemented as integrated, networked systems, in which case the benefits will be compounded. The railroad industry is urged to consider adopting an integrated approach when implementing these systems to achieve network-centric railroading.

A. Introduction

Intelligent railroad systems were first described in the Secretary of Transportation’s report, *The Changing Face of Transportation*,² published in 2000, and were expanded upon in the Federal Railroad Administration’s (FRA’s) *Five-Year Strategic Plan for Railroad Research, Development, and Demonstrations*,³ a report to Congress published in March 2002. The FRA, railroads, and the railroad supply industry have been working on the development of intelligent railroad systems for command, control, communications, and information (C³I), as well as for braking systems, grade crossings, defect detection, and planning and scheduling systems. These technologies can prevent collisions and overspeed accidents, prevent hijackings and runaways, increase capacity and asset utilization, increase reliability, improve service to customers, improve energy efficiency and emissions, increase economic viability and profits, and enable railroads to measure and control costs and to “manage the unexpected.”⁴ Intelligent railroad systems will enable railroads to improve their responsiveness to military deployments and to respond with flexibility and agility to rapid changes in the transportation marketplace.

Following the terrorist events of 9/11 2001, and especially following the terrorist bombings of trains in Madrid, Spain, on 3/11 2004, railroad security has received increased attention. Intelligent railroad systems will enable railroads to prevent some types of terrorist incidents from occurring, and, should incidents occur, these technologies will enable railroads to detect them, notify appropriate authorities, and recover more rapidly from the incidents. Railroads will have continuous, real-time information with which they can manage their operations.

¹ Alberts, David S. et al., *Network Centric Warfare: Developing and Leveraging Information Superiority*, Washington, DC: DoD Command and Control Research Program, 1999.

² Available on-line at: http://www.bts.gov/publications/the_changing_face_of_transportation/.

³ Available on-line at: <http://www.fra.dot.gov/us/content/225>. This paper is an amplification of Chapter 2, “A Vision for the Future: Intelligent Railroad Systems.”

⁴ Weick, Karl E. and Kathleen M. Sutcliffe, *Managing the Unexpected*, San Francisco: Jossey-Bass, 2001. The authors, two professors at the University of Michigan Business School, describe high-performance organizations that successfully “manage the unexpected” and explain why railroads today cannot be considered to be such organizations.

B. Network-Centric Railroading and the Intelligent Railroad Systems

Network-centric railroading is a “system of systems.” Following are descriptions of 29 technologies, programs, and systems, either developed or under development, which comprise intelligent railroad systems:

Digital data link communications networks provide the means for moving command and control instructions and general information to and from nodes throughout a railroad: locomotives, cars, maintenance-of-way vehicles, wayside interface units at switches and wayside detectors, train control centers, yards, intermodal terminals, passenger stations, maintenance facilities, and operating data systems. Customers and emergency responders will also be linked to the networks. Data link communications will replace or supplement many of today’s routine voice and fax communications with non-voice digital messages and will effectively increase the capacity of available communications circuits and frequencies. Voice communication will continue to take place, but it too will be carried over the digital network. Data link communications will utilize radio frequencies and mobile radios to communicate to, from, and between mobile assets, and will use a variety of transmission media (owned either by railroads or commercial telecommunications carriers) to communicate between fixed facilities. These media include microwave radio, fiber optic cable, buried copper cable, cellular telephones, communications satellites, traditional pole lines, and the Internet, and, with the mobile radios, they form an integrated communications network. Railroad communications control centers manage the integrity of the telecommunications network as well as its maintenance. With data link communications, the information is digitally coded and messages are discretely addressed to individual or multiple recipients. The US Government, through the Federal Communications Commission, has assigned to the railroad industry 182 frequencies in the VHF band (160 MHz) and 6 pairs of frequencies in the UHF band (900 MHz). The UHF frequencies are being used for digital communications, and some railroads have converted some of their assigned VHF frequencies from analog voice to digital communications. The conversion is expected to accelerate during the coming decade.

Nationwide Differential GPS (NDGPS) is an augmentation of the Global Positioning System (GPS) that provides 1- to 3-meter positioning accuracy⁵ to receivers capable of receiving the differential correction signal. It is an expansion of the US Coast Guard’s Maritime DGPS network which operates according to international standards⁶ that were developed by the Coast Guard and are used in over 45 nations. NDGPS makes use of decommissioned and converted US Air Force Ground Wave Emergency Network (GWEN) sites to calculate and broadcast the

⁵ 2001 *Federal Radionavigation Systems*, published by the Department of Defense (DoD) and the Department of Transportation (DOT), states, “The predictable accuracy of the NDGPS Service within all established coverage areas is better than 10 meters (2drms). NDGPS accuracy at each broadcast site is carefully controlled and is typically better than 1 meter. Achievable accuracy degrades at an approximate rate of 1 meter for each 150 km distance from the broadcast site. Accuracy is further degraded by computational and other uncertainties in user equipment and the ability of user equipment to compensate for other error sources such as multipath interference and propagation distortions. High-end user equipment may achieve accuracies better than 1 meter, throughout the coverage area, by compensating for the various degrading factors.”

⁶ Radio Technical Commission for Maritime Services RTCM SC-104 and International Telecommunications Union ITU-R M.823

differential correction signals in the low frequency band throughout the continental US. NDGPS receivers placed on locomotives and maintenance-of-way vehicles will calculate location, speed, and time, and that information will be shown on in-cab displays and transmitted back to the train control center over the railroad's digital data link communications network. NDGPS is now operational with single-station coverage over about 92 per cent (and with dual-station coverage over about 60 per cent) of the land mass of the continental US, and is expected to be fully operational with dual-station coverage in 2008 throughout the continental US and Alaska. To insure continuity, accuracy, reliability, and integrity, NDGPS is managed and monitored 24 hours a day, 7 days a week from the Coast Guard's Navigation Center in Alexandria, Virginia. NDGPS provides a GPS integrity monitoring capability; it gives an alarm to users within 5 seconds of detecting a fault with the signal from any GPS satellite. NDGPS signals are available to any user who acquires the proper receiver, and there is no user fee. Tests of an additional High Accuracy NDGPS (HA-NDGPS) signal to provide real-time 10- to 15-centimeter positioning accuracy have been conducted; further deployment of the signal is currently under consideration.

Positive Train Control (PTC) systems are integrated C³I systems for controlling train movements with safety, security, precision, and efficiency. PTC systems will improve railroad safety by significantly reducing the probability of collisions between trains, casualties to roadway workers and damage to their equipment, and overspeed accidents. The National Transportation Safety Board has had PTC on its "most wanted" list of transportation safety improvements since 1990.⁷ PTC systems are comprised of digital data link communications networks, continuous and accurate positioning systems such as NDGPS, on-board computers with digitized maps on locomotives and maintenance-of-way equipment, in-cab displays, throttle-brake interfaces on locomotives, wayside interface units at switches (both powered and manual) and wayside detectors, and train control center computers and displays. They will incorporate modules to permit them to record and retain the precise location, time, and circumstances of unplanned events such as derailments and grade crossing accidents. PTC systems also interface with tactical and strategic traffic planners, work order reporting systems, and locomotive health reporting systems. PTC systems issue movement authorities to train and maintenance-of-way crews, track the location of the trains and maintenance-of-way vehicles, have the ability to automatically enforce movement authorities, and continually update operating data systems with information on the location of trains, locomotives, cars, and crews. Current signal systems provide only a limited number of instructions (two to five different speed levels plus stop, conveyed by either one, two, or three colored lights) to train crews at widely spaced (2- to 20-mile) intervals; PTC can provide instructions to trains or maintenance-of way vehicles to operate at any speed, and can provide them at any location along the track. The remote intervention capability of PTC will permit the train control center to stop a train should the locomotive crew be incapacitated. With PTC, train spacing is no longer governed by fixed track blocks, but rather is determined by virtual, or moving, blocks based on train length, weight, and braking capability and track geometry. In addition to providing a greater level of safety and security, PTC systems also enable a railroad to run scheduled operations and provide improved running time, greater running time reliability, higher asset utilization, and greater track capacity.⁸ They will also assist railroads in measuring and managing costs and in

⁷ NTSB's "most wanted" list is found at the NTSB web site: http://www.nts.gov/Recs/mostwanted/rail_issues.htm

⁸ Zeta-Tech Associates, *Quantification of the Business Benefits of Positive Train Control*, Federal Railroad Administration, March 15, 2004. The authors calculated the internal rate of return for an investment in PTC for the

improving energy efficiency. Pilot versions of PTC (known then as the Advanced Railroad Electronics System (ARES) and the Advanced Train Control System (ATCS)) were successfully tested a decade ago, but the systems were never deployed on a wide scale.⁹ Other demonstration projects are currently in planning and testing stages in the US and in Europe. Deployment of PTC on railroads is expected to begin in earnest later this decade.

Electronically-controlled pneumatic (ECP) brakes – Current train air braking systems use air transmitted through a single brake pipe to both power the brakes and to transmit the signals to initiate brake applications and releases. As a result, air brake applications and releases are sequential along the length of a train. New ECP brakes use an electronic signal to initiate brake applications and releases, and thereby permit the simultaneous application of all brakes on a train, substantially shortening the braking distance and reducing in-train coupler forces and slack action. Shorter braking distances mean that trains can run faster, thereby increasing track capacity and improving asset utilization. ECP technology enables the air system to supply air continuously to each car for charging brakes, so brakes can be applied or eased as needed. This is not possible with current train air brakes.¹⁰ One ECP brake system under test uses a wire line along the train to convey the electronic signals from car to car, while another uses a spread spectrum radio on each car to convey the signals. The architecture of the wire line system is simpler and the cost is lower, but either type of system enables data to be collected from on-board equipment, track, and commodity sensors and moved to the locomotive where it will be displayed to the train crew and transmitted over the digital data link communications network to train control centers, maintenance facilities, and customers, as appropriate. ECP brakes have been tested on unit coal trains and double-stack intermodal container trains in the US, Canada, and Australia, and have been shown to improve train energy efficiency and train running time and to reduce wear on wheels and brake shoes. More widespread deployment of ECP brakes is expected in the coming decade.

Knowledge display interfaces – In-cab PTC displays will provide status information and command and control instructions to train crews in both graphic and textual form. They will display train position and speed as calculated by the positioning system, the upcoming route profile, speed limits and temporary slow orders, in-train forces, actual and recommended throttle and brake settings, speed control instructions and movement authorities as received over the data link from the train control centers, on-board locomotive health information from all locomotives on the train, and data from on-board and wayside equipment, track, and commodity sensors. The displays will incorporate a method for the train crew to acknowledge receipt of the speed control instructions and movement authorities. The displays will also show the train consist,¹¹ setout, pickup, and special handling instructions for cars from work order reporting systems; weight

US railroads as falling in the range of 44% to 160%, depending on costs of implementation and the capturing of benefits.

⁹ Hertenstein, Julie H. and Robert S. Kaplan, *Burlington Northern: The ARES Decision (A) and (B)*. Boston, MA: Harvard Business School, Cases 9-191-122 and 9-121-123, 1991.

¹⁰ See Chapter 5, “Challenges and Promise” in DeBoer, David J. and Lawrence H. Kaufman, *An American Transportation Story*, Greenbelt, Maryland: Intermodal Association of North America, 2002.

¹¹ A “train consist” (pronounced CON-sist) is a list, in sequence, of the specific locomotives and cars that comprise a train, and includes train and car length and weight, car type, loaded or empty status, car contents, routing, special handling requirements, and destination.

distribution along the length of the train; data from the end-of-train device and ECP brakes; and any other information that will be sent over the data link. Train control center displays for dispatchers will show the precise location and speed of each train and maintenance-of-way vehicle, train consists, locomotive health, performance against schedule, and the plans generated by the tactical and strategic traffic planners. The challenge in developing the displays is to insure that all necessary information, and no unnecessary information, is displayed. Liquid crystal and plasma screens currently being installed on locomotives and at train control centers have the capability to display the information that will be generated by the intelligent railroad systems.

Crew registration and time-keeping systems will use identification techniques such as the Department of Homeland Security's proposed Transportation Worker Identification Credential, other electronic card keys, passwords, or biometrics such as fingerprints and retinal scans to insure that only authorized crew members are permitted to control locomotives and maintenance-of-way vehicles. The train control center will issue a movement authority only when it has confirmation that the designated crew is on board and logged in. The times that train crew members log on duty on the locomotive, depart their initial terminal, arrive at their final terminal, and log off duty will be automatically sent over the digital data link communications network to the train control center and to the operating data system. This will eliminate manual record-keeping and data entry chores and insure that accurate times are entered in the operating data system for payroll purposes.

Crew alertness monitoring systems promote on-duty alertness and vigilance of train crews through the use of non-invasive technology applications. Mental lapses and other human errors that result in unsafe safe job performance are often due to reduced alertness or vigilance. Real time monitoring and feedback of *individual alertness levels* will allow crew members to modify their behavior and reduce their risk of unsafe performance. Risk-appropriate countermeasures, such as napping, social interaction, and postural changes, will be suggested by the system, and in the case of high risk (e.g., the crewmember falls asleep), the system will both notify the train control center over the digital data link communications network and stop the train. Real time monitoring and feedback of *population alertness levels* will allow managers to dynamically adjust work schedules and help ensure the most well-rested individuals, or teams, are available for high-risk assignments. Models of fatigue and alertness in the system will accurately predict future risk of non-alertness in individuals and groups of individuals so that countermeasures can be applied to maintain optimal performance either before or throughout a work shift. A complete implementation of PTC would reduce the necessity for crew alertness monitoring systems.

Track forces terminals (TFTs) provide the means for moving information and instructions to and from roadway workers and maintenance-of-way vehicles. A TFT consists of a laptop computer or personal digital assistant (PDA), data radio, and positioning system receiver. The TFT sends position reports from the field to the train control center over the digital data link communications network, and it displays authorities received from the train control center to the roadway workers. With a TFT, roadway workers will obtain authorities without talking to a dispatcher. The TFT will display the location of all trains in the vicinity, and the crew will determine when the track will be unoccupied and use the TFT to request track occupancy for that time. The train control center computer checks the proposed authority for safety, and if it is safe,

the dispatcher grants the authority which then appears automatically on the dispatcher's display and on the TFT. At the completion of track work, the TFT can be used to place a slow order (temporary speed restriction) on the track by transmitting the information to the train control center computer. The TFT will also be used to transmit administrative data (e.g., gang time, machine usage and status, material usage and requirements, and production reporting information) to track maintenance facilities and the railroad operating data system. TFTs should significantly improve the productivity of roadway worker crews without compromising safety. They will allow them to plan their access to the track and obtain longer "windows" to accomplish their work.

Automatic Equipment Identification (AEI) tags, also known as radio frequency identification (RFID) tags, have been installed on both sides of all freight cars and locomotives in the US and Canada since 1995. The requirement was established by a railroad industry consensus standard, not by FRA regulation.¹² AEI readers, installed along the track at yards, terminals, and junctions, interrogate the tags over UHF radio frequency (900 MHz), and the tags respond to the readers with the unique alphanumeric code identifying each car and locomotive. The readers assemble the information from all locomotives and cars on a train and then transmit the entire train consist to the railroad's operating data system over the digital data link communications network or over dedicated telephone lines. Because PTC systems know at all times the precise location of every train, AEI, when combined with PTC, permits railroads to know at all times the precise location of every car and shipment. Some railroads have installed substantial numbers of readers and have integrated them with their operating data systems; others have not. Installation and integration of the full network of readers is expected in the next few years. AEI readers will also be integrated with wayside equipment sensors to provide positive identification of vehicles with defects.

Wayside equipment sensors are installed along the track to identify a number of defects that occur on rolling stock components and to transmit information about the defects so that trains will be stopped if necessary and maintenance crews can perform repairs as required. Among the defects that will be detected by the wayside sensors are overheated bearings and wheels, deteriorating bearings, malfunctioning brakes, built-up wheel treads, worn wheels, cracked wheels, flat wheels, derailed wheels, excessive truck hunting, dragging equipment, excessive lateral and vertical loads, skewed trucks, and excessively high and wide loads. AEI readers integrated with the sensors provide positive identification of vehicles with defects. Information from the sensors is now usually transmitted to train crews by voice-synthesized VHF radio. Once data link communications networks are installed, the information will be transmitted from wayside interface units at the sensors to train crews, train control centers, and maintenance facilities. The Association of American Railroads' (AAR's) Integrated Railway Remote Information Service (InteRRISTM) consists of a network of wayside equipment sensors with

¹² Association of American Railroads Standard S-918-94, effective March 1, 1992, was based on a draft standard developed by the International Standards Organization (ISO) for AEI tags on containers. There are, at present, voluntary AEI tagging standards for containers (by the ISO) and truck trailers and chassis (by the American Trucking Associations), and they are compatible with the AAR standard for railroad vehicles. If these voluntary standards were to become mandatory, railroads would be able to automatically track the location of containers and trailers when they are being transported on railcars.

integrated AEI readers that send data to a central computer that analyzes the data for trends and sends out appropriate alerts and warnings to railroads and car owners. A railroad can have access to data regarding all cars, regardless of ownership, on its own track, as well as data regarding all of its cars on other railroads' track.

Wayside track sensors are installed to identify a number of defects that occur on and alongside the track as well as identify conditions and obstructions along the track and to transmit the information so that the train will be stopped or slowed if necessary and maintenance crews will perform repairs as required. Among the conditions and defects that will be detected by wayside sensors are switch position, broken rail, misaligned track, high water, rock and snow slides, excessive rail stress, misaligned bridges and trestles, blocked culverts, earthquakes, and general security and integrity information regarding track and structures. Information from such sensors is now usually transmitted to train crews by wayside signal indication. Once data link communications networks are installed, the information will be transmitted from wayside interface units at the sensors to train crews, train control centers, and maintenance facilities.

Locomotive health monitoring systems consist of sensors mounted on engines, traction motors, electrical systems, air systems, exhaust systems, and fuel tanks on locomotives. Most new locomotives are equipped with most of these sensors. Today, the data from all units in the train consist are displayed to locomotive crews and collected in on-board computers for retrieval when locomotives arrive at maintenance facilities. In the future, the data will be transmitted over the digital data link communications network to train control centers, maintenance facilities, and motive power distribution centers to permit real-time monitoring of locomotive performance and efficiency, improved diagnosis of problems, and more effective assignment of locomotives to trains. Each of those centers and facilities could make an inquiry over the data link to a locomotive to receive a health status report. Data generated by the locomotive health monitoring systems will also be collected at maintenance facilities and analyzed to permit maintenance to be done on an as-needed rather than on an arbitrary time schedule. Traction motor performance in both traction and dynamic braking modes will be monitored. Locomotive health monitoring systems will improve locomotive utilization, save time in maintenance facilities, and keep trains on schedule. They will also improve locomotive energy efficiency and emissions. Limited testing of real-time locomotive health monitoring has taken place over the last decade. Event recorders for after-the-fact investigations will record throttle and brake information collected by the monitoring systems and combine it with the precise location and time information generated by the NDGPS receivers.

Energy management systems (EMSs) are separate computer programs installed on locomotives to optimize fuel consumption and/or emissions. An EMS will receive information on track profile and conditions, speed limits, the train consist including train length and weight, locomotive engine fuel performance characteristics, information from the locomotive health monitoring systems on engine and traction motor performance, and target times at specific locations as determined by the tactical traffic planner. It will then determine a recommended train speed that meets service requirements while minimizing fuel consumption and/or emissions and providing good train-handling characteristics. Conceptual work has been done on EMSs, but a prototype system has not yet been implemented.

Vehicle-borne track monitoring sensors installed on inspection cars, and perhaps eventually on locomotives, identify a number of track geometry and rail integrity conditions so that trains can be stopped or slowed if necessary and maintenance crews can perform repairs as required. Among the defects that will be detected by the on-board sensors are rail flaws, broken rail, misaligned track, and excessive rail stress. Ride quality data can also be collected with accelerometers and used to determine track misalignment. Information from all these sensors, combined with precise location and time information generated by the NDGPS receivers, will be displayed in the inspection car or locomotive cab and will be transmitted from the car or locomotive via the digital data link communications network to train control centers, maintenance crews, and maintenance facilities.

Car on-board component sensors installed on rolling stock identify a number of defects and provide information so that the train can be stopped if necessary and maintenance crews can perform repairs as required. Among the defects and conditions that will be detected by the on-board sensors are overheated bearings and wheels, impacts and vibrations from flat or derailed wheels or corrugated track, excessive truck hunting, excessive longitudinal forces, and braking system status. Information from the sensors will be transmitted over the ECP brake system's communications channel to the locomotive where it will be observed by the train crew and transmitted over the digital data link communications network to train control centers and maintenance facilities. Some development and testing of these sensors has occurred, but deployment of a digital data link communications network and ECP brakes is a prerequisite for the installation of such sensors.

Car on-board commodity sensors are being installed on freight cars to monitor the status of the commodities being carried. Among the parameters that can be measured by the on-board sensors are temperatures, pressures, vibrations, load position, radiation, gases, and biohazards. The security of shipments will also be monitored. The presence of stowaways in closed cars, containers, and trailers can also be determined. Information from the sensors will be transmitted over the ECP brake system's communications channel to the locomotive where it will be observed by the train crew and transmitted over the digital data link communications network to train control centers, maintenance facilities, and customers. The sensors could also be queried from trackside interrogators. If problems are detected, the train will be stopped and maintenance crews will perform repairs. Some customers and freight car owners are now using proprietary sensor and satellite communications packages to obtain the data, including location information, directly from the cars, bypassing railroad information channels.

Intelligent grade crossings – Intelligent Transportation Systems (ITS) for roadways interact with intelligent railroad systems at highway-rail intersections (HRIs). Information about train location and arrival times, generated either by a PTC system or track circuits or off-track sensors, will be transmitted from train control centers to highway traffic control centers via the digital data link communications network, to motor vehicle operators, cyclists, and pedestrians via roadside traffic information signs, and to motor vehicle operators also via dedicated short-range communications (DSRC) radios to in-vehicle displays or audio warning systems. Similarly, sensors at HRIs will send information to train control centers and trains over the digital data link

communications network should an HRI be blocked by an accidentally or intentionally stalled vehicle. Demonstrations of intelligent grade crossing devices have been conducted in eight states. Architecture elements to describe the HRIs have been added to the ITS National Architecture,¹³ and work on the development of standards for intelligent grade crossings has been started to insure that there will be national interoperability.

Intelligent weather systems consist of networks of local weather sensors and instrumentation—both wayside and on-board locomotives—combined with national, regional, and local forecast data to alert train control centers, train crews, and maintenance crews of actual or potential hazardous weather conditions. The sensors will collect information on temperature, atmospheric pressure, rate of change of temperature and pressure, precipitation, and wind speed and direction and transmit it over the digital data link communications network to train control centers. It will provide advance and real-time warning of weather-caused hazards such as flooding; track washouts; snow, mud, or rock slides; high winds; fog; high track-buckling risk; or other conditions which require adjustment to train operations or action by maintenance personnel. Weather data collected on the railroad will also be automatically forwarded to government and commercial weather forecasting centers to augment their other data sources. The installation of a digital data link communications network is a prerequisite for this activity. Intelligent weather systems are included in the ITS National Architecture.

Tactical traffic planners (TTPs) produce plans showing when trains should arrive at each point on a dispatcher's territory, where trains should meet and pass, and which trains should take sidings. As the plans are executed, a TTP takes the very detailed train movement information provided by the PTC system and compares it with desired train performance. If there are significant deviations from plan, the TTP will re-plan, adjusting meet and pass locations to recover from undesired lateness, taking into account weather conditions, traffic patterns, and track and train speed limits. "Pacing" instructions can be sent to a train to call for a speed reduction to avoid stopping and restarting. TTPs make use of sophisticated non-linear optimization techniques to devise an optimal dispatching plan that reduces the time that trains wait at passing sidings on single-track lines and at crossovers on multiple-track lines. Once a TTP prepares a plan, the dispatcher need only accept it. Then the computer-assisted dispatching system of PTC produces all authorities needed to execute the plan and sends them over the digital data link communications network to trains and maintenance-of-way vehicles. Some prototype TTPs have been developed and tested.

Strategic traffic planners (STPs) – TTPs cannot function without knowing the schedule for each train. STPs measure train movements against a set of externally-defined schedules which include information on scheduled block swaps and connections, both internal and with other railroads and other transportation modes. Integrating a flow of information about actual train performance from the TTP, the performance of connections, and detailed consist information for all trains from operating data systems, STPs make cost-minimizing decisions on whether, and how, train priorities and schedules might be adjusted on a real-time basis. STPs are the highest-

¹³ The ITS National Architecture, developed by the ITS Joint Program Office, US DOT, is available on-line at: <http://www.its.dot.gov/arch/arch.htm>.

level real-time control system in the PTC hierarchy. STPs will be able to display the performance of trains against schedule, the real-time location of every train by type (e.g., coal, intermodal, grain, intercity passenger), and the location of trains at future times based on current performance. The Federal Aviation Administration has implemented an STP called the “Enhanced Traffic Management System” to provide central flow control for the National Airspace System; the same philosophy will apply to STPs for railroads.

Yard management systems (YMSs) provide the essential link between the movement of trains and the movement of cars. The YMS will receive real-time information on the location and make up of each train on the system and will keep track of all cars in the yard. It will receive goals and objectives from the STP. This will allow the YMS to determine the best way to make up trains, that is, the time sequence in which arriving cars should be classified, the time sequence in which they should be pulled from the lead tracks, and the time and physical sequence in which outbound trains should be made up. The YMS will account for the time that trains will be arriving, the times they should be departing, and the time required for each yard operation to be performed. It will supply a forecast of yard departure times for each of the trains to the STP so that it will be able to perform better its job of creating time targets for smooth system functioning.

Work order reporting systems send instructions over the digital data link communications network from the train control center to train crews regarding the setting out and picking up of loaded and empty cars enroute. When crews acknowledge accomplishment of work orders, the system automatically updates the on-board train consist information and transmits information on car location and train consists back over the digital data link communications network to the railroad’s operating data system and to customers. Work order reporting information will be displayed in locomotives on the same screens that will display PTC instructions and information. One major railroad has deployed a work order reporting system using a dedicated digital data link communications network.

Locomotive scheduling systems use data regarding train schedules, physical terrain, locomotive characteristics, locomotive health information, locomotive servicing and maintenance schedules, and expected train consists to assign locomotives to trains, making use of linear programming algorithms. Improved train consist information coming from a car scheduling and reservation system will result in better locomotive allocations. Keeping trains and, therefore, locomotives on schedule is necessary to execute future locomotive assignments. Locomotive scheduling systems have been developed and are in use on most railroads. Providing the locomotive scheduling systems with real-time information on locomotive health, current and future locations of trains, and expected train consists will significantly improve the utilization rate of locomotives.

Car reservation and scheduling systems – Freight car reservation systems allow customers to reserve freight car capacity and routing in advance; freight car scheduling allows railroads to plan the movements of individual freight cars to match up with known customer demand. Scheduling of the movement of cars will reduce cross-hauling of empty cars and reduce delays to loads and empties at intermediate yards. This reduces fleet size requirements and improves asset utilization. Car reservation and scheduling systems, which are similar to airline seat reservation

and scheduling systems, can only work when railroads operate on a schedule, and, in turn, car reservation and scheduling systems provide information to locomotive scheduling systems and are a prerequisite for yield management. One major railroad developed and used a car scheduling system for a number of years. However, the railroad's inability to keep its trains on schedule meant that cars often had to be reassigned to different trains in the course of their journeys.

Train crew scheduling systems – When train operations are scheduled and stay on schedule, train crew assignments can also be scheduled a number of days or weeks in advance. That will result in predictable work hours for most crew members, and will enable them to schedule regular periods of sleep and recreation, reducing family and social tensions and emotional and physical stress and fatigue. Train crew scheduling systems will use information from the STP and from PTC along with information about crew members (seniorities, current locations, schedule preferences, most recent assignment worked) and Hours of Service Act and labor contract provisions to match up trains and crews most cost-effectively. Some European railroads currently use such long-term train crew scheduling systems.

Yield management systems enable railroads to establish variable pricing policies which maximize profit by linking the price charged for a service to customer demand. Applicable to both freight and passenger railroad operations, yield management requires reservation and scheduling capabilities, and sophisticated information systems to keep track of changing capacity, complex service variables, and multiple prices. With yield management, railroads can identify opportunities for filling up existing capacity with lower-priced services for customers who are less service-sensitive. At the same time, it will show when and how much to increase prices for service-sensitive customers shipping or traveling at peak times. Amtrak and all major airlines use yield management systems to enhance their revenues.

Security systems consisting of closed-circuit television (CCTV) cameras and infrared presence detectors are being deployed at bridges and tunnels, and even on some locomotives, to provide detection of intruders and obstructions. At present, the images and alarms are monitored by railroad police security centers that notify railroad and local police field forces to respond on site as necessary. At some sites, a loudspeaker is installed with the camera and detectors to permit the security center to notify intruders to depart the premises. As the number of such CCTV and detector installations increases, the images and data will be combined on large, clickable maps. Anything that moves will get an icon on the maps. Digital borders and automated image processing systems will be used to determine the presence of undesired persons or objects. Information from other sensors (infrared, chemical sniffers, RFID) will appear on the maps, supplying details humans can not otherwise see.¹⁴ Appropriate information will be transmitted via data link to train control centers and train and maintenance crews in addition to security forces.

Emergency notification systems installed at train control centers provide for the automated notification of all involved organizations following railroad accidents, incidents, or threats. They

¹⁴ "The All-in-One Widescreen Security Cam", *Wired*, March 2005, p. 28.

provide for better coordination and control of the involved organizations: railroad response crews; police, fire, and emergency medical services, as well as other appropriate local, state, and national authorities. The systems are tied to geographical interfaces. When reports of accidents, incidents, or threats arrive over the digital data link communications network with precise and accurate geographical coordinates, the emergency notification system can identify the correct emergency responders for that locale, notify them, and provide them with accurate location information. The systems monitor the timing of the call-outs and the arrival of emergency services at the scene so that performance can be analyzed. The systems enable the faster resolution of problems and resumption of rail service.

Travelers advisory systems use real-time train location information generated by GPS receivers on locomotives and transmitted over digital data links to provide intercity passenger train and commuter train riders with expected arrival times of their trains. The information is displayed on dynamic message boards at stations and on map displays posted on the Internet. The information is used by the passenger railroads, which are often tenants on freight railroads, to automatically collect data on the on-time performance of their trains. These systems are typically implemented as free-standing systems using cellular or satellite communications, but they will be integrated with other systems, using information from the PTC system and transmitting it over the railroad's digital data communications network.

C. Human Factors Issues

The development of the various displays being developed for PTC systems, including the Knowledge Display Interfaces for train crews and dispatchers and the TFTs for roadway workers, will require the involvement of railroad employees and human factors professionals to insure that the displays provide the proper information content and form to permit the employees to carry out their jobs in an optimal fashion. The displays should provide all the information the employees need, and only the information the employees need, and they should provide it in the most comprehensible manner. The graphic display, in addition to the textual display, of movement authorities should help train crew members understand the authorities and prevent misunderstandings. Crew alertness monitoring systems enable railroads to monitor the stress and fatigue of train crews. Comprehensive training programs are required for train crews and railroad maintenance personnel on the use of all the new systems. The scheduling of trains and the implementation of train crew scheduling systems will significantly reduce stress and fatigue of train crews.

PTC and digital data link communications will also reduce stress and fatigue of dispatchers by reducing their communication load, improving their communication efficiency and speed, increasing their communication precision, and changing their communication focus from information-gathering and movement authorization to traffic planning and problem solving.¹⁵ Data link communications will supplement, but not eliminate, voice radio communications.

The management structure of railroads, and the flow of information within that structure, will

¹⁵ Ditmeyer, Steven R. and Michael E. Smith, "Data Links and Planning Tools: Enhancing the Ability to Plan and Manage Train Operations," *Rail International*, April 1993, pp. 69-77.

have to be aligned with the new systems to enable railroads to take advantage of new information and the digital communications network. The implementation teams that are established for intelligent railroad systems need to have representatives from all departments on the railroad that will be affected by the implementation. Some railroads have tried to implement projects with teams that are too small, and, as a result, implementation of those projects has been less than fully successful. In order for management to get “buy-in” from each department, each department needs to know it is appropriately represented on the implementation team.

One railroad demonstrated two approaches to implementing a locomotive health monitoring system. At one locomotive maintenance facility, the superintendent announced that the purpose of the system was to better monitor the performance of the shop mechanics. At another facility, the superintendent said that the purpose of the system was to improve the performance of the locomotives they serviced. At the first facility the employees fought the system, while the second facility was recognized as having the best performing locomotive fleet on the railroad. Clearly, attention needs to be paid to how these new systems are presented to the work force.

D. System Security and Information Assurance

An overarching issue that affects the design and deployment of network-centric railroading and intelligent railroad systems is the security of information. It must be incorporated in intelligent railroad systems before deployment. Data regarding trains, cars, crews, and shipments must be kept secure, and unwarranted extraction of information from the digital data link communications network must be prevented. Authentication of data insures that content is genuine, unaltered, and complete. Encryption is the security mechanism that converts plaintext into cyphertext that is unintelligible to those who do not have access to the appropriate key. Archiving of data from intelligent railroad systems must also be done in a secure manner through the control of access privileges to prevent loss of data.

E. Security Benefits

In addition to safety and business benefits, network-centric railroading with intelligent railroad systems enhances the security of railroad operations and protection of critical infrastructure elements by providing railroad domain awareness. PTC systems monitor of location and speed of all trains, provide on-board enforcement of all movement authorities, and have the ability to remotely intervene to stop trains. Wayside track sensors provide the capability to monitor all switches (both powered and manual), bridges, and tunnels, and wayside interface units transmit their status to train control centers. Intelligent grade crossing systems can determine if highway-rail intersections are blocked by accidentally and intentionally stalled vehicles, and notify trains. Crew registration systems insure that only authorized crew members are permitted to control locomotives and maintenance-of-way vehicles. Car on-board commodity sensors and wayside equipment sensors provide additional information about the integrity of shipments, questionable cargoes, and the presence of stowaways.

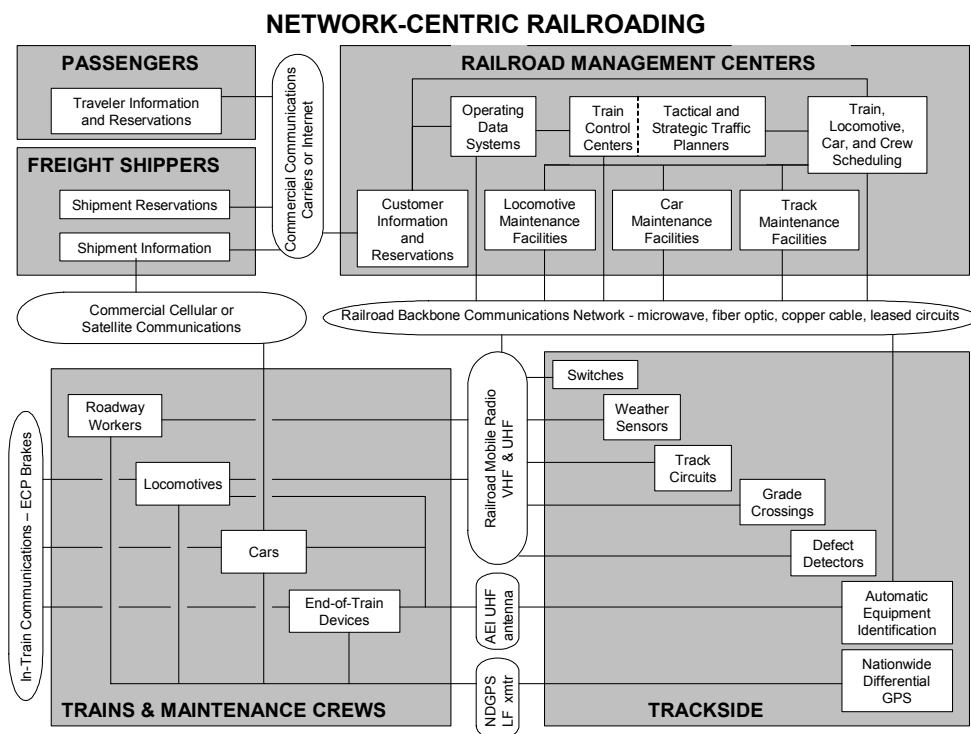
When waybill databases (showing car contents, shipper, and consignee), the Umler file,¹⁶ and

¹⁶ Umler is the uniform machine language equipment register, maintained by Railinc, a subsidiary of the AAR, and provided to each railroad. It is a data file containing identification, ownership, and physical information for every freight car in service on the US and Canadian railroads.

databases receiving data from PTC systems (location of trains), AEI systems (train consists), and work order reporting systems (cars at customers, in yards, and on repair tracks) are integrated, railroads can monitor the precise location of all cars and all shipments, and especially hazmat shipments, at all times, and provide that information on a need-to-know basis to their customers and appropriate government agencies. CCTV systems provide visual images of critical infrastructure for monitoring at railroad police security centers. Emergency notification systems enable train control centers to identify and verify emergencies and to provide notification of emergencies to emergency responders, hospitals, public sector authorities, and railroad officials.

F. The Architecture of Network-Centric Railroading

The following figure illustrates a preliminary architecture for network-centric railroading, showing how the intelligent railroad systems fit together and identifying the key communications links for standardization. It is a top-level interconnect diagram and is based on conventions developed by the Architecture Development Team for the ITS National Architecture. This type of diagram is known as a “sausage diagram” in which the “sausages” represent the various communications links that move information between nodes in the gray rectangles representing crews and vehicles, fixed installations along the railroad rights-of-way, control and management centers, and customers. The links can be owned by railroads or by commercial telecommunications carriers and they can be microwave radio, fiber optic cable, buried copper cable, cellular telephones, communications satellites, traditional pole lines, and the Internet.



G. Impediments to Implementation

The implementation of network-centric railroading with intelligent railroad systems is not without impediments. Major ones are the magnitude of the costs, the availability of capital to the railroad industry, and the competition for capital within railroad companies. Railroads need to understand that a well-executed investment in intelligent railroad systems, by increasing asset utilization, will reduce the capital needed for locomotives, cars, and track. Also, PTC may actually be less costly than in-kind replacement of existing signaling systems. The FRA's Railroad Rehabilitation and Improvement Financing (RRIF) program¹⁷ and the DOT's Transportation Infrastructure Financing and Innovation Act (TIFIA) program are potential sources of funds for network-centric railroading and intelligent railroad systems.

In the early 1990's, railroad chief executives considered the implementation of PTC, ECP brakes, and other intelligent railroad systems, but decided instead to use available railroad capital for mergers and acquisitions, believing that the mergers and acquisitions would yield a higher rate of return. The mergers, which resulted in four large railroads that carry over 90 percent of the rail freight in the US, were not well executed, however, and did not generate forecasted returns. Consequently, the major railroads do not believe they have the capital needed for investment in network-centric railroading and intelligent railroad systems. In fact, several of the large railroads are struggling to handle recent increases in freight traffic caused by the economic recovery, increased imports, the truck driver shortage, and highway congestion. However, they are investing in the construction of double-track, which provides capacity benefits in only a limited territory, rather than in tools to help them better manage their traffic flows over their entire network. Most senior railroad managers received their management experience in an environment of downsizing and cost-cutting; few have experience managing growth.

When railroads perform cost-benefit analyses for capital investment decisions, they separate benefits into two categories: "hard" benefits consisting of reductions in staff and fuel consumption and "soft" benefits consisting of improved running times, greater reliability, improved services, increased revenues, and the like. The soft benefits are often discounted heavily. Railroads have been viewing PTC recently more as a mechanism for reducing train crew size rather than increasing track capacity and improving asset utilization. Railroads also feel they are under pressure by the investment community to deliver near-term rather than long-term returns on their investments.

The implementation options for intelligent railroad systems are varied; not all railroads will want to invest in all of the systems. Some railroads use improper decision criteria to establish the architecture of new systems. They seek to minimize the cost of specific subsystems rather than optimize the benefits and costs of the entire system. One major railroad instructed its contractor to design a PTC system that would minimize the cost of telecommunications (by minimizing the number of messages transmitted); another wanted the cost of locomotive on-board systems minimized. Such decisions will, by raising other costs or reducing functionality, result in ineffective deployment or no deployment at all. Yet another railroad implemented several of the intelligent railroad systems – specifically train location, locomotive health reporting, and work

¹⁷ The RRIF program is proposed for elimination in the *Fiscal Year 2006 Budget of the United States Government*.

order reporting – but used a dedicated communications channel and radio for each system rather than having them share a common channel and radio. The challenge with intelligent railroad systems is for a railroad to optimize the relationship between total system benefits and total system costs, not just subsystem benefits and subsystem costs.

Some railroads want the logic of new PTC systems to be the same as the logic of their existing operating rule books and signaling systems, which is based on knowledge of which track blocks are occupied. PTC systems, based on a new and different paradigm with knowledge of the precise location and speed of all trains and maintenance-of-way vehicles, can provide closer headways and greater capacity while simultaneously increasing safety. Furthermore, while the investment in traditional wayside signal systems is completely along the track, the largest portion of an investment in PTC is in equipment on locomotives and maintenance-of-way vehicles, with smaller portions going into equipment along the track and at the train control centers.

A tension exists between investments in legacy systems and modern systems. Some members of the railroad signaling community—railroad signal engineers and signal maintainers, signal suppliers, and signal regulators—point out that PTC systems do not automatically incorporate broken-rail protection, which is integral with track circuit-based signal systems. That is correct; with PTC, the decision to incorporate broken rail protection is a separate, independent decision. The signaling community is also skeptical of PTC systems because they feel that PTC systems have less reliable components (e.g., radios, NDGPS receivers, on-board computers, liquid crystal and plasma displays, etc.) than traditional wayside signaling systems, whose components are all very robust and reliable, having been designed to meet fail-safe standards. However, the reliability of components is not the sole determinant of system safety. The architecture of existing signaling and train control systems is such that it permits one person, either a locomotive engineer or a dispatcher, to make a mistake (because of fatigue, illness, drugs, inattention, distraction, carelessness, or some other reason) that can cause two trains to collide. The safety of PTC systems derives from an integrated architecture that provides checks and balances which limit the impact and propagation of human error. Analyses have shown that the probability of a collision or overspeed accident occurring with PTC is one-one hundredth of the probability of a collision occurring with existing signaling systems.¹⁸

Railroads are currently not organized well for implementing intelligent railroad systems. The groups responsible for telecommunications and for train control systems are often in disparate parts of railroad organizations. Telecommunications staff often report to the information systems department, while train control staff often report to the track engineering and maintenance department. Network-centric railroading requires that telecommunications and train control staffs either be amalgamated or have an extremely close working relationship.

Some railroads are reluctant to write off, or to view as sunk costs, investments in physical assets such as wayside signal systems that would no longer be needed when PTC systems are

¹⁸ Weinstein, William W., Philip S. Babcock IV, and Frank Leong, *Safety Analysis of ARES*, Cambridge, MA: The Charles Stark Draper Laboratory, Inc., October 1987, Report CSDL-R-2013, for Burlington Northern Railroad; and Weinstein, William W. and Andrei L. Schor, *Safety Analysis of the ATCS*, Cambridge, MA: The Charles Stark Draper Laboratory, Inc., April 1990, Report CSDL-R-2098, Rev. 1, for the AAR.

implemented. Rather, they want to incorporate as much of their “legacy” technology as possible into new command and control systems.

Interoperability issues affect some but not all of the intelligent railroad systems. Locomotives equipped with radios using common frequencies and protocols, with common positioning systems, and with computers using common logic are necessary if PTC is to be implemented widely. Since the two types of ECP brake systems are not interoperable, the railroad industry must decide which will be the industry standard. Other systems, such as tactical and strategic traffic planners, locomotive health monitoring systems, work order reporting systems, and wayside equipment sensors, do not require railroad industry agreement.

Some railroads see a barrier in the cost of getting started. Because PTC is a locomotive-based rather than track-based system, they believe that all locomotives have to be converted at once because of the difficulty in assigning equipped locomotives to specific territories. However, those same railroads currently assign their AC-traction locomotives to specific heavy-haul territories. Since implementation of PTC will take place region-by-region, PTC-equipped locomotives could be phased in and managed on a region-by-region basis.

Network-centric railroading may take a decade or more to implement, well beyond the tenure of many senior railroad executives. Most railroad senior managers have received their promotions because of their success in downsizing facilities and operations; few have experience in managing growth. Railroads today lack staff with knowledge of these new technologies; additional staff with the proper skills will have to be hired or trained with an extensive professional capacity building program.

Some railroads are reluctant to acknowledge that intelligent railroad systems would result in safer operations because of concerns about the liability that they could incur should accidents happen before the installation of the systems is completed or on lines where the systems are not installed.¹⁹ Railroad lawyers also seem concerned that the availability of data from intelligent railroad systems could be detrimental to railroad interests if they had to provide it to plaintiffs’ attorneys in court trials.

When new technologies are adopted and when methods of operation change, it is only natural that some individuals, and even institutions, will be resistant to change. Those with knowledge of signal systems feel threatened by the adoption of a different train control technology. Some in management will want to move the new, different, and more complete information through the existing stovepipes of the hierarchical structure, rather than directly to those managers and

¹⁹ A similar situation existed in the 1930’s, shortly after Automatic Train Control (ATC), a system to enforce wayside signal indications, was developed to address the problem of collisions involving passenger trains. Congress passed, and President Franklin D. Roosevelt signed into law, the Railroad Signal Inspection Act of 1937 which directed the Interstate Commerce Commission (ICC, which was responsible for railroad safety regulation until the FRA was created in 1967) to order the installation of ATC when it was determined to be necessary in the public interest. However, the law also specified that railroads were not to be held negligent for not installing ATC on portions of their track not covered by ICC orders. This law remains on the books, and could conceivably be applied to the implementation of PTC.

operators who can take immediate action based on the information. The US military encountered this problem during Operation Iraqi Freedom.²⁰

Some railroads have expressed concern about DoD control of GPS. They are reluctant to implement train control systems that rely on GPS, or augmented GPS, for train location, speed, and time information because of concerns that DoD may unilaterally degrade or terminate GPS signals during a time of war or national emergency.

Suppliers are reluctant to invest much money in the development of intelligent railroad systems without some assurance that railroads will commit funds to deploy them. In fact, railroad managements have argued that since there are no off-the-shelf intelligent railroad systems, they cannot implement them. Because the FRA recognizes this situation, it sponsors R&D and demonstrations for a number of the components of intelligent railroad systems. However, until railroads decide that they want to implement these systems, and demonstrate their commitment with contracts with suppliers, development of some of the systems will be delayed.

Some railroad marketing departments have expressed uncertainty about the response of their customers to service improvements that might result from the implementation of intelligent railroad systems. Those marketing departments doubt their customers' willingness to pay more for better service, or to shift more traffic from highways to railroads. Even though the railroads have little data to show their customers' elasticity of demand for significantly improved service, they have substantial data showing their customers' responses when railroad service deteriorated and recovered following the recent mergers.

Quite often, railroad managements require that individual departments provide the justifications for proposed capital investment projects because, historically, the costs and benefits of a project have accrued to the same department. For example, mechanical departments provide the justifications for investments in new locomotives and maintenance facilities, and engineering departments provide the justifications for investments in tunnel elimination and bridge replacement projects. Many, if not most, of the intelligent railroad systems would generate benefits that would accrue to departments other than the department that installed them. If intelligent railroad systems are to be implemented, railroads must also establish new, broader-based capital planning and budgeting processes that recognize the integrated nature of these systems and that there are multiple beneficiaries of each system.

The breaking up of railroads into separate operating and infrastructure companies, a trend now occurring in Europe and a trend that some urge be adopted in the US, could be a further impediment to the implementation of intelligent railroad systems. The costs and the benefits of the individual systems will not fall in the same proportions between operating companies and infrastructure companies. Negotiating processes involving engineers, economists, financial analysts, and lawyers would have to be established to allocate costs and benefits among the new entities. These processes, while not impossible, would add complexity to any deployment of intelligent railroad systems.

²⁰ Talbot, David, "How Tech Failed in Iraq," *Technology Review*, Vol. 107, No. 9, November 2004, pp. 36-44.

Finally, some railroads are reluctant to invest in intelligent railroad systems, and especially PTC and ECP brakes, before they know what safety regulations will be issued by the FRA, and the regulatory process there can be long and tortuous. It has taken FRA over seven years to issue a rule on PTC. Some railroads are reluctant to test and evaluate such systems, lest the FRA finds that the systems improve railroad safety and efficiency and issues new regulations mandating the implementation of the systems.²¹ In a move seemingly made to fend off such regulations, one railroad told the FRA that the quality of its operations was so good that there was no room for any improvement. Recently, the AAR went on record with the FRA stating that they believe the benefits to the railroad industry from the application of PTC and related systems are less than the costs.²² The logic of this is not clear, since the investment in PTC will be in lieu of, not in addition to, current railroad spending on signaling systems. It appears that PTC will be less costly than signaling systems it replaces, while offering significant benefits not offered by the existing systems.

H. Conclusion

All these issues and impediments can appear daunting to the organizations that are faced with the implementation of network-centric railroading with intelligent railroad systems. Furthermore, the deployments of ITS, new air traffic control systems, maritime vessel tracking systems, and even the military's network-centric warfare are not occurring without some complications. Nevertheless, network-centric railroading is key to making railroad operations – freight, intercity passenger, and commuter – safer, reducing delays, reducing costs, raising effective capacity, increasing reliability, improving customer satisfaction, improving energy utilization, reducing emissions, increasing security, and making railroads more economically viable.

Network-centric railroading will enable railroads to manage unexpected situations by providing real-time information about current operations and the current environment. That will enable managers and dispatchers to have more knowledge of the status of the entire railroad, thereby enhancing operational security and the protection of critical infrastructure. Information will flow to the right people who have the ability to take corrective actions.

Railroad customers, including the US military services, will benefit significantly from the improved running time and service reliability resulting from the implementation of network-centric railroading. Railroads face the challenge of capturing some of those benefits in the form of increased revenues.

²¹ Many railroads, and some officials of the FRA, believe that only safety benefits can be used to justify an FRA regulation. However, Executive Order 12866, "Regulatory Planning and Review," dated September 30, 1993, states; "Further, in choosing among alternative regulatory approaches, agencies should select those approaches that maximize net benefits (including potential economic, environmental, public health and safety, and other advantages; distributive impacts; and equity), unless a statute requires another regulatory approach."

²² *Comments of the Association of American Railroads on the Report by the Federal Railroad Administration Entitled "Benefits and Costs of Positive Train Control,"* presented to the FRA at the meeting of the Railroad Safety Advisory Committee, Washington, DC, April 27, 2004.

Network-centric railroading and intelligent railroad systems, as described in this paper, represent a “unified theory of railroading.” Intelligent railroad systems can either be implemented as independent systems, in which case their benefits will be limited, or they can be implemented as integrated, networked systems, in which case the benefits will be compounded. The railroad industry is urged to consider adopting an integrated approach when implementing these systems to achieve network-centric railroading.

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